



Thesis On

ADVANCE TECHNIC OF RECTANGULAR MICROSTRIP PATCH ANTENNA WITH EBGs

A Thesis submitted to the Eastern University in fulfillment of the requirement for the degree of Bachelor of Science in Electrical and Electronic Engineering.

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Statement of Originality

We hereby certify that the content of this thesis is the result of work done by us and has not been submitted for a higher degree to any other University or Institution.

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Chapter 1

MICROSTRIP PATCH ANTENNA

1.1 Introduction

Communication between humans was first by sound through voice. With the desire for slightly more distance communication came, devices such as drums, then, Visual methods such as signal flags and smoke signals were used. These optical communication devices, of course, utilized the light portion of the electromagnetic spectrum. It has been only very recent in human history that the electromagnetic spectrum, outside the visible region, has been employed for communication, through the use of radio. One of humankind's greatest natural resources is the electromagnetic spectrum and the antenna has been instrumental in harnessing this resource.

1.2 Aim and Objectives

Microstrip patch antenna used to send onboard parameters of article to the ground while under operating conditions. The aim of the thesis is to design and fabricate an inset-fed rectangular Microstrip Patch Antenna and study the effect of antenna dimensions Length (L), Width (W) and substrate parameters relative Dielectric constant (ϵ_r), substrate thickness (t) on the Radiation parameters of Bandwidth and Beam-width.

1.3 Antenna

An antenna changes radio signals in the air into electricity, or vice versa. Antennas send signals, receive signals, or both. All NETGEAR wireless devices have an antenna, either a visible pole on the outside, or inside where you do not see it. The distance that an antenna *sends* (transmits) depends on the type, and the amount of power running through it.

1.4 Antenna Characteristics

An antenna is a device that is made to efficiently radiate and receive radiated electromagnetic waves. There are several important antenna characteristics that should be considered when choosing an antenna for your application as follows:

- Antenna radiation patterns
- Power Gain
- Directivity
- Polarization

1.5 Overview of Microstrip Antennae

A microstrip antenna consists of conducting patch on a ground plane separated by dielectric substrate. This concept was undeveloped until the revolution in electronic circuit miniaturization and large-scale integration in 1970. After that many authors have described the radiation from the ground plane by a dielectric substrate for different configurations. The early work of Munson on micro strip antennas for use as a low profile flush mounted antennas on rockets and missiles showed that this was a practical concept for use in many antenna system problems. Various mathematical models were developed for this antenna and its applications were extended to many other fields. The number of papers, articles published in the journals for the last ten years, on these antennas shows the importance gained by them. The micro strip antennas are the present day antenna designer's choice.

Low dielectric constant substrates are generally preferred for maximum radiation. The conducting patch can take any shape but rectangular and circular configurations are the most commonly used configuration. Other configurations are complex to analyze and require heavy numerical computations. A microstrip antenna is characterized by its Length, Width, Input impedance, and Gain and radiation patterns. Various parameters of the microstrip antenna and its design considerations were discussed in the subsequent chapters. The length of the antenna is nearly half wavelength in the dielectric; it is a very critical parameter, which governs the resonant frequency of the antenna. There are no hard and fast rules to find the width of the patch.

1.6 Microstrip Patch Antenna

Microstrip antennas are attractive due to their light weight, conformability and low cost. These antennas can be integrated with printed strip-line feed networks and active devices. This is a relatively new area of antenna engineering. The radiation properties of micro strip structures have been known since the mid 1950's. The application of this type of antennas started in early 1970's when conformal antennas were required for missiles. Rectangular and circular micro strip resonant patches have been used extensively in a variety of array configurations. A major contributing factor for recent advances of microstrip antennas is the current revolution in electronic circuit miniaturization brought about by developments in large scale integration. As conventional antennas are often bulky and costly part of an electronic system, micro strip antennas based on photolithographic technology are seen as an engineering breakthrough.

In its most fundamental form, a Microstrip Patch antenna consists of a radiating patch on one side of a dielectric substrate which has a ground plane on the other side as shown in Figure 1.1. The patch is generally made of conducting material such as copper or gold and can take any possible shape. The radiating patch and the feed lines are usually photo etched on the dielectric substrate.

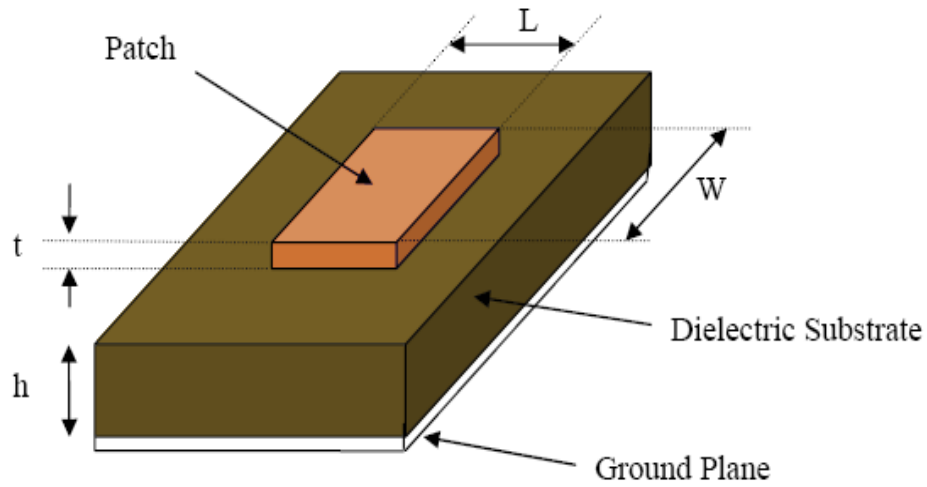


Figure 1.1 Structure of a Microstrip Patch Antenna

In order to simplify analysis and performance prediction, the patch is generally square, rectangular, circular, triangular, and elliptical or some other common shape as shown in Figure 1.2. For a rectangular patch, the length L of the patch is usually $0.3333\lambda_o < L < 0.5\lambda_o$, where λ_o is the free-space wavelength. The patch is selected to be very thin such that $t \ll \lambda_o$ (where t is the patch thickness). The height h of the dielectric substrate is usually $0.003\lambda_o \leq h \leq 0.05\lambda_o$. The dielectric constant of the substrate (ϵ_r) is typically in the range $2.2 \leq \epsilon_r \leq 12$.

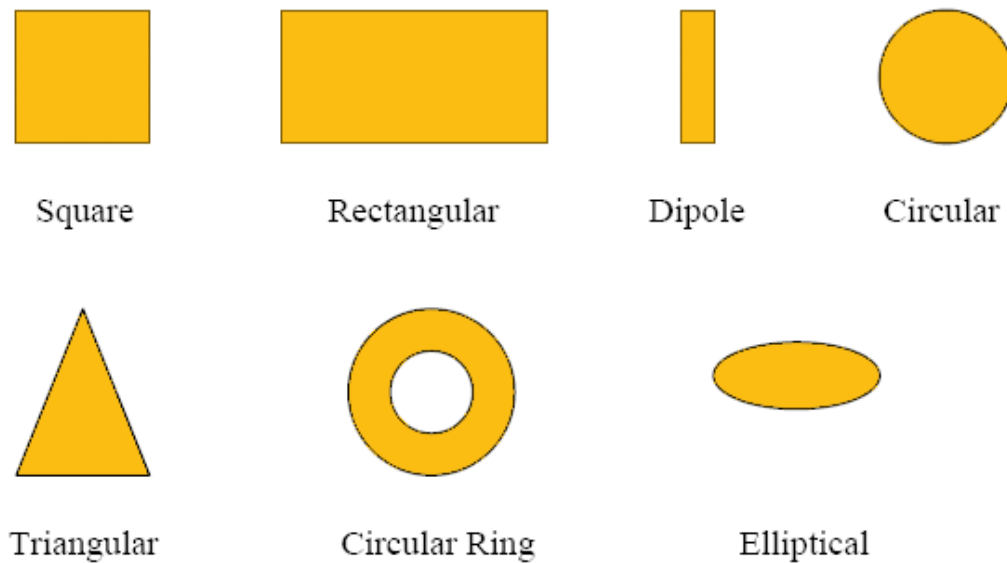


Figure 1.2 Common shapes of microstrip patch elements

Microstrip patch antennas radiate primarily because of the fringing fields between the patch edge and the ground plane. For good antenna performance, a thick dielectric substrate having a low dielectric constant is desirable since this provides better efficiency, larger bandwidth and better radiation. However, such a configuration leads to a larger antenna size. In order to design a compact Microstrip patch antenna, substrates with higher dielectric constants must be used which are less efficient and result in narrower bandwidth. Hence a trade-off must be realized between the antenna dimensions and antenna performance.

1.6.1 Advantages and Disadvantages

Microstrip patch antennas are increasing in popularity for use in wireless applications due to their low-profile structure. Therefore they are extremely compatible for embedded antennas in handheld wireless devices such as cellular phones, pagers etc. The telemetry and communication antennas on missiles need to be thin and conformal and are often in the form of Microstrip patch antennas. Another area where they have been used successfully is in Satellite communication. Some of their principal advantages discussed by Kumar and Ray are given below:

- Light weight and less volume.
- Low fabrication cost, therefore can be manufactured in large quantities.
- Supports both, linear as well as circular polarization.
- Low profile planar configuration which can be easily made conformal to host surface.
- Can be easily integrated with microwave integrated circuits (MICs).
- Capable of dual and triple frequency operations.
- Mechanically robust when mounted on rough surfaces.

Microstrip patch antennas suffer from more drawbacks as compared to conventional antennas.

Some of their major disadvantages are given below:

- Narrow bandwidth
- Low efficiency
- Low Gain
- Low power handling capacity.
- Surface wave excitation
- Extraneous radiation from feeds and junctions
- Poor end fire radiator except tapered slot antennas

Microstrip patch antennas have a very high antenna quality factor (Q). It represents the losses associated with the antenna where a large Q leads to narrow bandwidth and low efficiency. Q can be decreased by increasing the thickness of the dielectric substrate. But as the thickness increases, an increasing fraction of the total power delivered by the source goes into a surface wave.

Chapter 2

FEED TECHNIQUE AND BANDWIDTH

2.1 Feed Techniques

Microstrip patch antennas can be fed by a variety of methods. These methods can be classified into two categories- contacting and non-contacting. In the contacting method, the RF power is fed directly to the radiating patch using a connecting element such as a microstrip line. In the non-contacting scheme, electromagnetic field coupling is done to transfer power between the microstrip line and the radiating patch. The four most popular feed techniques used are the microstrip line, coaxial probe (both contacting schemes), aperture coupling and proximity coupling (both non-contacting schemes).

2.1.1 Microstrip Line Feed

In this type of feed technique, a conducting strip is connected directly to the edge of the Microstrip patch as shown in Figure 2.1. The conducting strip is smaller in width as compared to the patch and this kind of feed arrangement has the advantage that the feed can be etched on the same substrate to provide a planar structure.

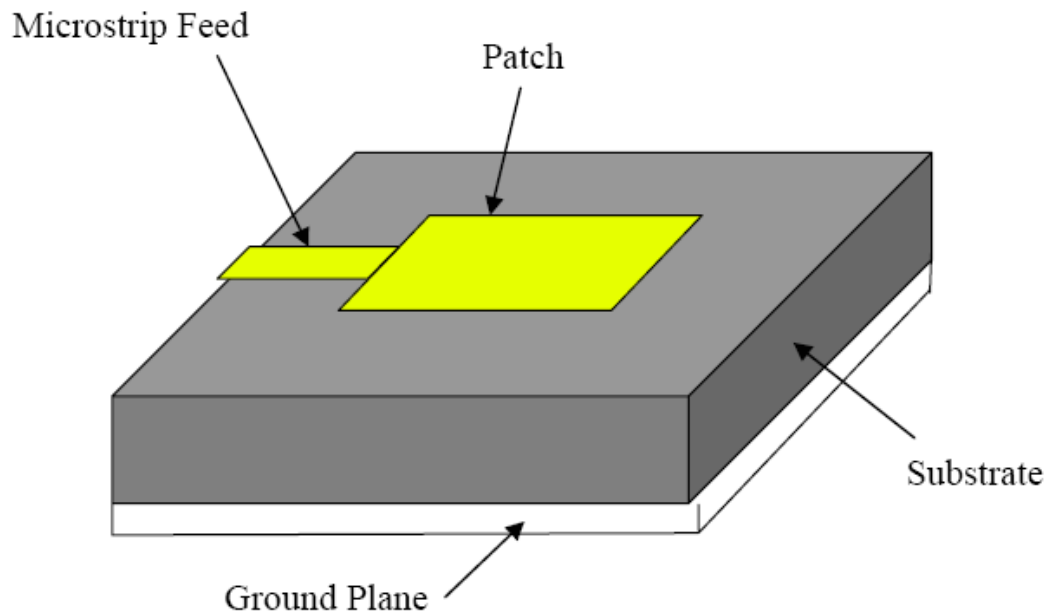


Figure 2.1 Microstrip Line Feed

The purpose of the inset cut in the patch is to match the impedance of the feed line to the patch without the need for any additional matching element. This is achieved by properly controlling the inset position. Hence this is an easy feeding scheme, since it provides ease of fabrication and simplicity in modeling as well as impedance matching.

However as the thickness of the dielectric substrate being used, increases, surface waves and spurious feed radiation also increases, which hampers the bandwidth of the antenna. The feed radiation also leads to undesired cross polarized radiation.

2.1.2 Coaxial Feed

The Coaxial feed or probe feed is a very common technique used for feeding Microstrip patch antennas. As seen from Figure 2.2, the inner conductor of the coaxial connector extends through the dielectric and is soldered to the radiating patch, while the outer conductor is connected to the ground plane.

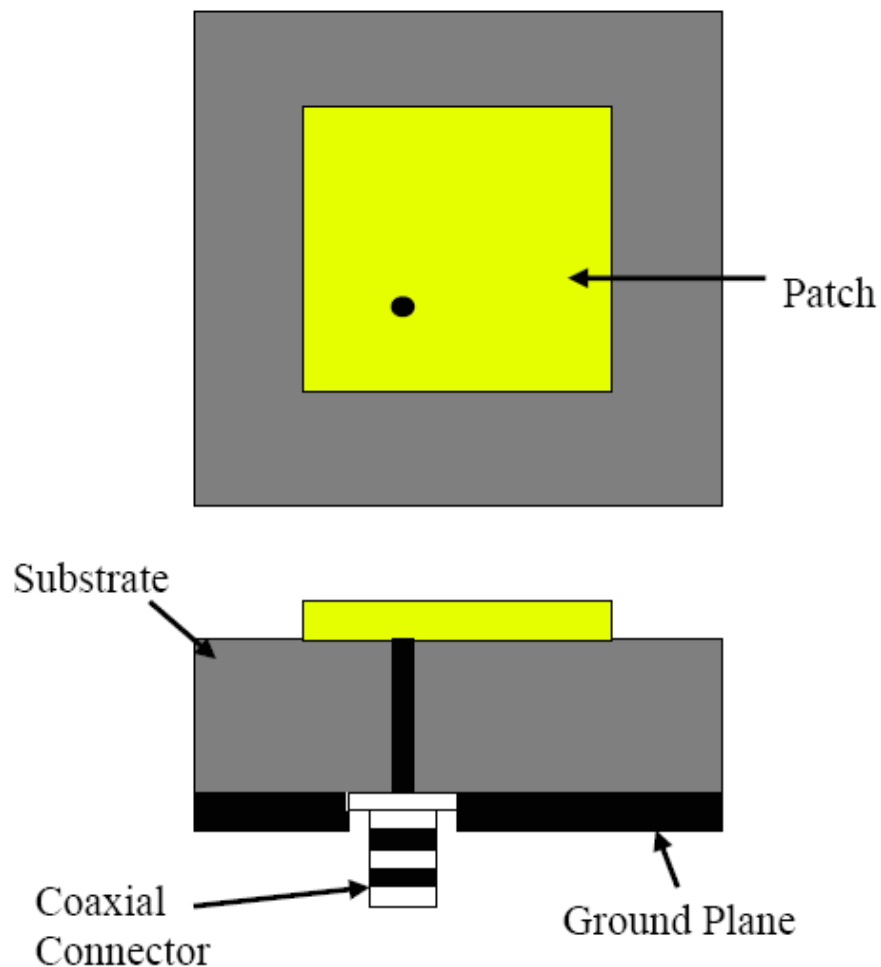


Figure 2.2 Probe fed Rectangular Microstrip Patch Antenna

The main advantage of this type of feeding scheme is that the feed can be placed at any desired location inside the patch in order to match with its input impedance. This feed method is easy to fabricate and has low spurious radiation. However, a major disadvantage is that it provides narrow bandwidth and is difficult to model since a hole has to be drilled in the substrate and the connector protrudes outside the ground plane, thus not making it completely planar for thick substrates ($h > 0.02\lambda_0$). Also, for thicker substrates, the increased probe length makes the input impedance more inductive, leading to matching problems. It is seen above that for a thick dielectric substrate, which provides broad bandwidth, the microstrip line feed and the coaxial feed suffer from numerous disadvantages. The non-contacting feed techniques which have been discussed below, solve these issues.

2.1.3 Aperture Coupled Feed

In this type of feed technique, the radiating patch and the microstrip feed line are separated by the ground plane as shown in Figure 2.3. Coupling between the patch and the feed line is made through a slot or an aperture in the ground plane.

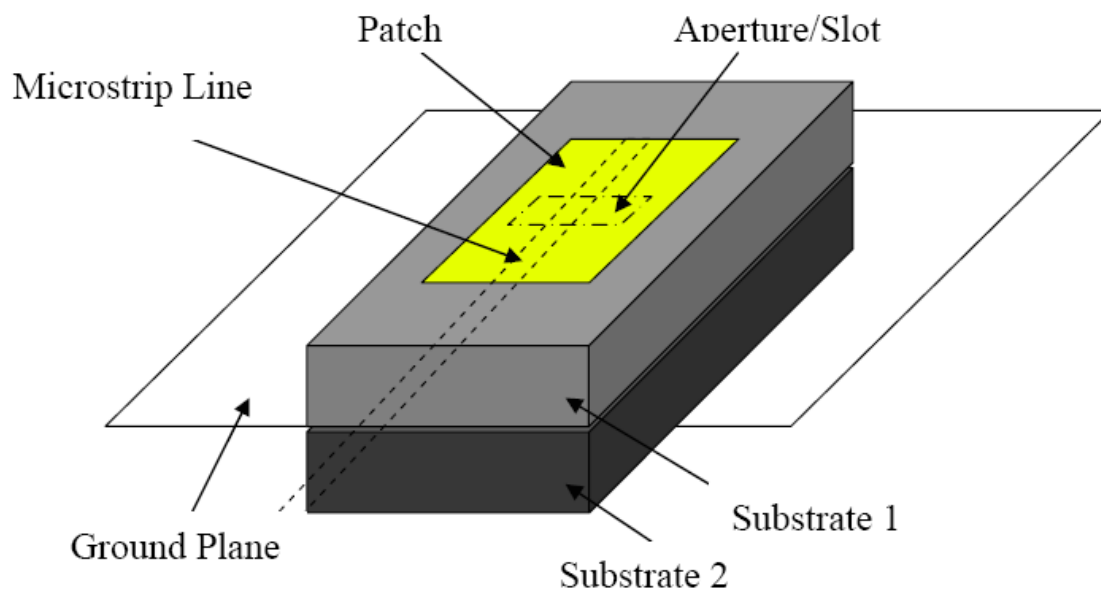


Figure 2.3 Aperture-coupled feed

The coupling aperture is usually centered under the patch, leading to lower cross polarization due to symmetry of the configuration. The amount of coupling from the feed line to the patch is determined by the shape, size and location of the aperture. Since the ground plane separates the patch and the feed line, spurious radiation is minimized.

Generally, a high dielectric material is used for bottom substrate and a thick, low dielectric constant material is used for the top substrate to optimize radiation from the patch. The major disadvantage of this feed technique is that it is difficult to fabricate due to multiple layers, which also increases the antenna thickness. This feeding scheme also provides narrow bandwidth.

2.1.4 Proximity Coupled Feed

This type of feed technique is also called as the electromagnetic coupling scheme. As shown in Figure 2.4, two dielectric substrates are used such that the feed line is between the two substrates and the radiating patch is on top of the upper substrate. The main advantage of this feed technique is that it eliminates spurious feed radiation and provides very high bandwidth (as high as 13%), due to overall increase in the thickness of the microstrip patch antenna. This scheme also provides choices between two different dielectric media, one for the patch and one for the feed line to optimize the individual performances.

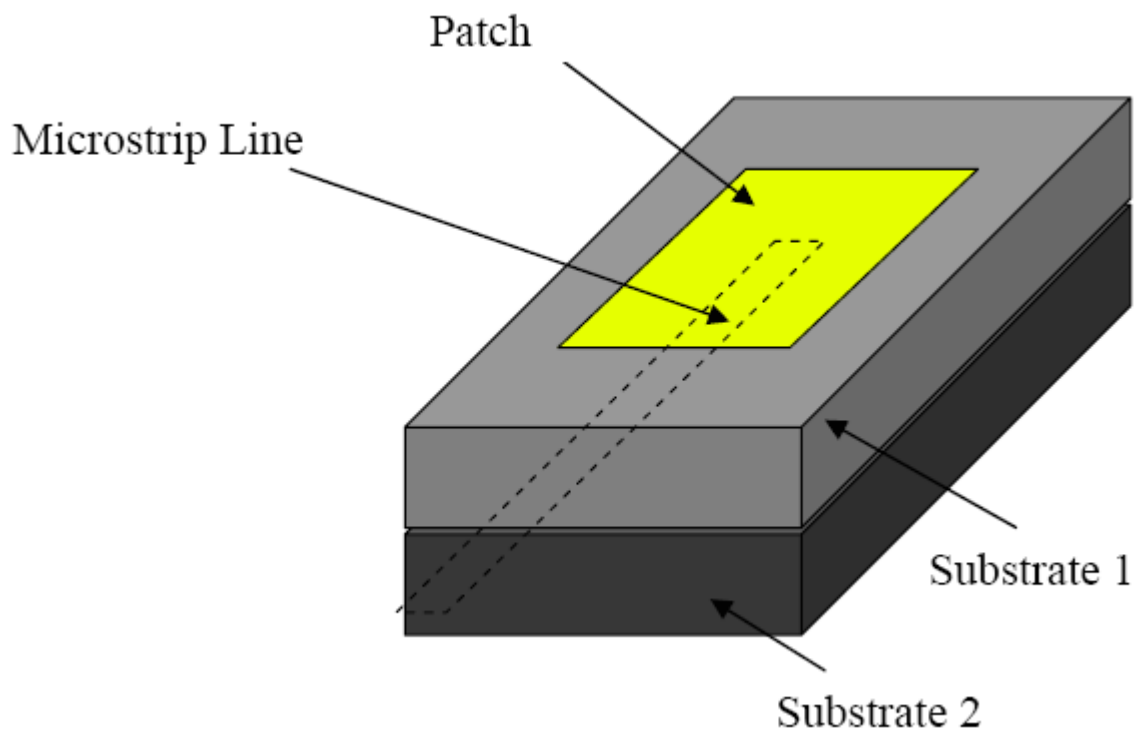


Figure 2.4 Proximity-coupled Feed

Matching can be achieved by controlling the length of the feed line and the width to line ratio of the patch. The major disadvantage of this feed scheme is that it is difficult to fabricate because of the two dielectric layers which need proper alignment. Also, there

2.2 Methods of Analysis

The preferred models for the analysis of Microstrip patch antennas are the transmission line model, cavity model, and full wave model (which include primarily integral equations/Moment Method). The transmission line model is the simplest of all and it gives good physical insight but it is less accurate. The cavity model is more accurate and gives good physical insight but is complex in nature. The full wave models are extremely accurate, versatile and can treat single elements, finite and infinite arrays, stacked elements, arbitrary shaped elements and coupling. These give less insight as compared to the two models mentioned above and are far more complex in nature.

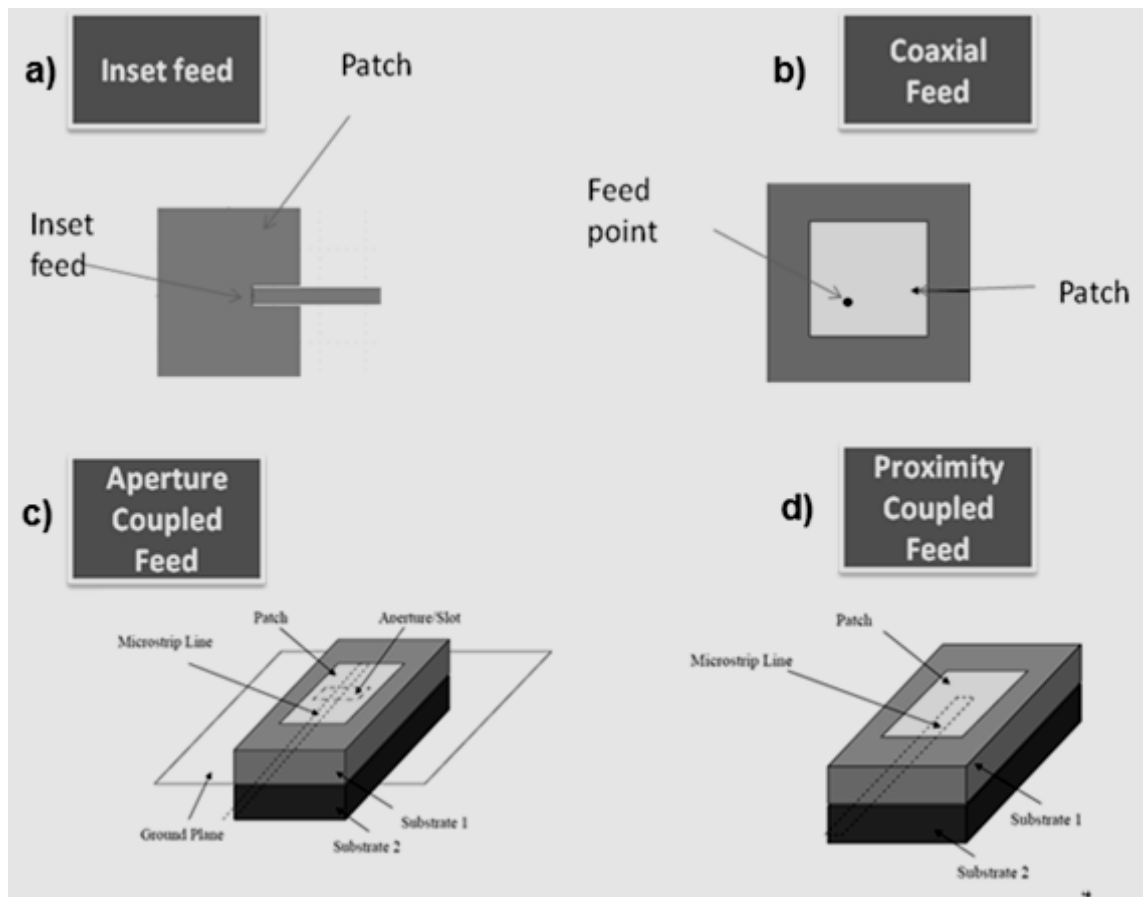


Figure 2.5: Comparison of different feed techniques

characteristics	Microstrip line feed	Coaxial feed	Aperture coupled feed	Proximity coupled feed
Spurious feed radiation	More	More	Less	Minimum
Reliability	Better	Poor due to soldering	Good	Good
Ease of fabrication	Easy	Soldering and Drilling needed	Alignment Required	Alignment Required
Impedance matching	Easy	Easy	Easy	Easy
Bandwidth	2-5%	2-5%	21%	13%

Table 2.1 Comparison of different feed techniques

2.3 Transmission Line Model

This model represents the microstrip antenna by two slots of width W and height h , separated by a transmission line of length L . The microstrip is essentially a non homogeneous line of two dielectrics, normally the substrate and air.

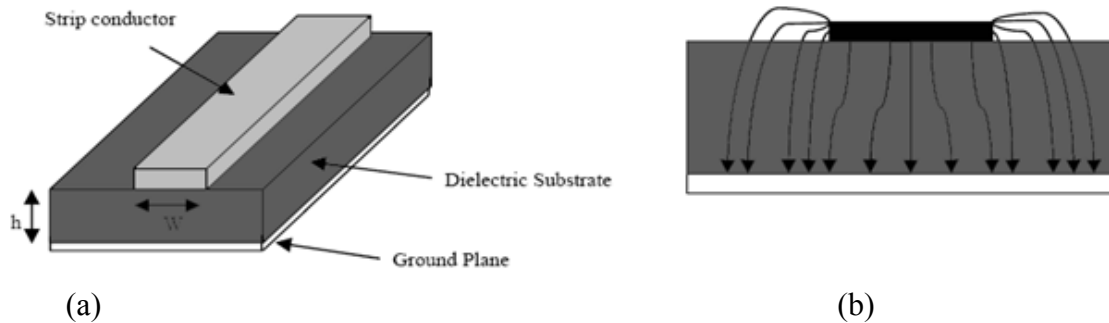


Figure 2.6 (a) Microstrip Line (b) Electric Field Lines

Hence, as shown in Figure.2.6 (b), most of the electric field lines lies in the substrate and parts of some lines are in air. As a result, this transmission line do not support pure transverse electromagnetic mode of transmission, since the phase velocities would be different in the air and the substrate. Instead, the dominant mode of propagation would be the quasi-TEM mode. Hence, an effective dielectric constant (ϵ_{eff}) must be obtained in order to account for the

fringing and the wave propagation in the line. The value of ϵ_{eff} is little less than ϵ_r because the fringing fields around the edge of the patch are not confined in the dielectric substrate but are also spread in the air as shown in Figure above. The expression for ϵ_{eff} can be given as:

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[1 + 12 \frac{h}{W} \right]^{-\frac{1}{2}}$$

Where,

ϵ_{eff} = Effective dielectric constant

ϵ_r = Dielectric constant of substrate

H = Height of dielectric substrate

W = Width of the patch

Consider Figure 2.7, which shows a rectangular microstrip patch antenna of length L , width W lying on a substrate of height h . The co-ordinate axis is selected in such a way that the length is along the x axis direction, width is along the y axis direction and the height is along the z axis direction.

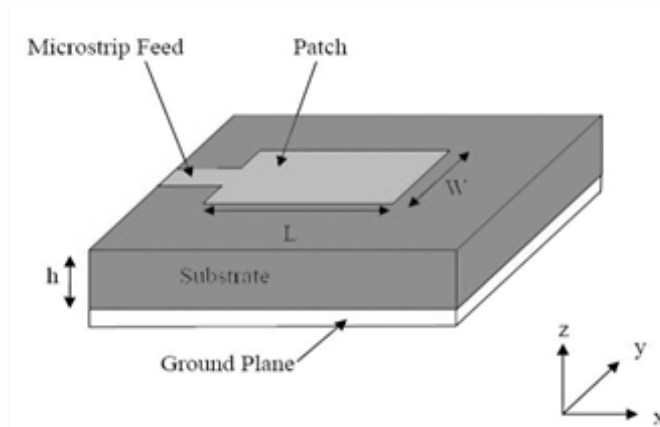


Figure 2.7 Microstrip Patch Antenna

In order to operate in the TM_{10} mode, the length of the patch must be slightly less than $\lambda/2$ where λ is the wavelength in the dielectric medium and is equal to $\lambda_0/\sqrt{\epsilon_{eff}}$ where λ_0 is the free space wavelength. The TM_{10} mode implies that the field varies one $\lambda/2$ cycle along the length, and there is no difference along the width of the patch. In the Figure 2.7, the microstrip patch antenna is shown by two slots and separated by a transmission line of length L and open circuited at both the ends. Along the width of the patch, the voltage is maximum and current is minimum due to the open ends. The fields at the edges can be resolved into normal and tangential components with respect to the ground plane.

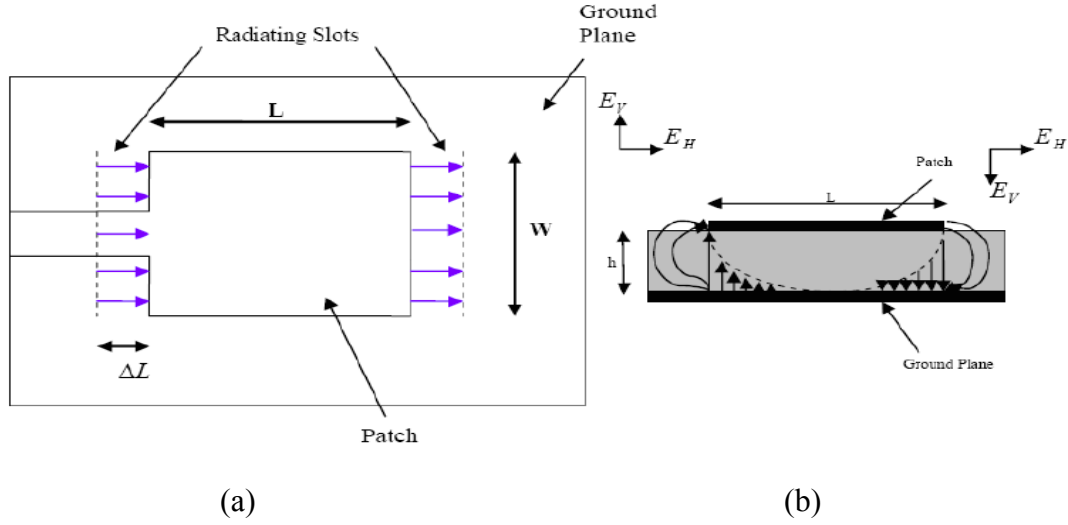


Figure 2.8 (a) Top View of Antenna (b) Side View of Antenna

It is shown in Figure 2.8.b that the normal components of the electric field at the two edges along the width are in opposite directions and thus out of phase since the patch is $\lambda/2$ long and hence they nullify each other in the broadside direction. The tangential components which are in phase, means that the resulting fields combine to give maximum radiated field normal to the surface of the structure. Hence the edges along the width can be represented as two radiating slots, which are $\lambda/2$ apart and excited in phase and radiating in the half space above the ground plane.

The fringing fields along the width can be modeled as radiating slots and electrically the patch of the microstrip antenna looks greater than its physical dimensions. The dimensions of the patch along its length have now been extended on each end by a distance ΔL , which is given empirically as:

$$\Delta L = 0.412h \frac{(\epsilon_{r_{eff}} + 0.3) \left(\frac{W}{h} + 0.264 \right)}{(\epsilon_{r_{eff}} - 0.258) \left(\frac{W}{h} + 0.8 \right)}$$

The effective length of the patch L_{eff} now becomes:

$$L_{eff} = L + 2\Delta L$$

For a given resonance frequency f_0 , the effective length is given by as:

$$L_{eff} = \frac{c}{2f_0 \sqrt{\epsilon_{r_{eff}}}}$$

For a rectangular Microstrip patch antenna, the resonance frequency for any TM_{mn} mode is given by as:

$$f_o = \frac{c}{2\sqrt{\epsilon_{reff}}} \left[\left(\frac{m}{L} \right)^2 + \left(\frac{n}{W} \right)^2 \right]^{\frac{1}{2}}$$

Where m and n are modes along L and W respectively for efficient radiation, the width W is given as;

$$W = \frac{c}{2f_o \sqrt{\frac{(\epsilon_r + 1)}{2}}}$$

2.4 Properties of a Basic Microstrip Patch

A microstrip or patch antenna is a low profile antenna that has a number of advantages over other antennas it is lightweight, low cost, and easy to integrate with accompanying electronics. While the antenna can be 3D in structure (wrapped around an object, for example), the elements are usually flat; Hence their other name, planar antennas. Note that a planar antenna is not always a patch antenna.

The figure 2.9 shows a patch antenna in its basic form: a flat plate on a ground plane. The center conductor of a coax serves as the feed probe to couple electromagnetic energy in and/or out of the patch. The electric field distribution of a rectangular patch in its fundamental mode is also shown

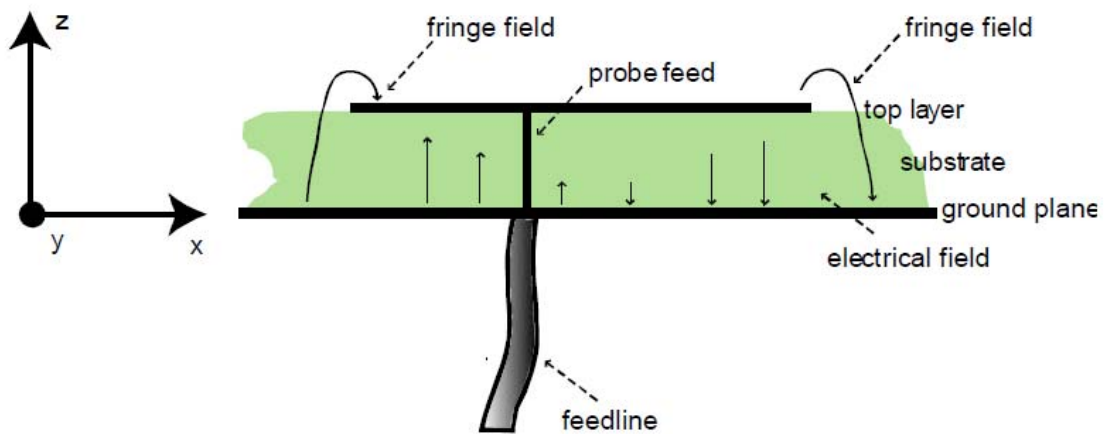


Figure 2.9 Basic Microstrip patch antenna with probe feeding

The electric field is zero at the center of the patch, maximum (positive) at one side, and minimum (negative) on the opposite side. It should be mentioned that the minimum and maximum continuously change side according to the instantaneous phase of the applied signal. The electric field does not stop abruptly at the patch's periphery as in a cavity rather; the fields extend the outer periphery to some degree. These field extensions are known as fringing fields and cause the patch to radiate. Some popular analytic modeling techniques for patch antennas are based on this leaky cavity concept. Therefore, the fundamental mode of a rectangular patch is often denoted using cavity theory as the TM₁₀ mode.

Since this notation frequently causes confusion, we will briefly explain it. TM stands for transversal magnetic field distribution. This means that only three field components are considered instead of six. The field components of interest are: the electric field in the z direction and the magnetic field components in x and y direction using a Cartesian coordinate system, where the x and y axes is parallel with the ground plane and the z axis is perpendicular.

In general, the modes are designated as TM_{nmz}. The z value is mostly omitted since the electric field variation is considered negligible in the z axis.

Hence TM_{nm} remains with n and m the field variations in x and y direction. The field variation in the y direction (impedance width direction) is negligible; Thus m is 0. And the field has one minimum to maximum variation in the x direction (resonance length direction) ; Thus n is 1 in the case of the fundamental. Hence the notation TM₁₀.

2.5 Dimensions

The resonant length determines the resonant frequency and is about 1/2 for a rectangular patch excited in its fundamental mode. The patch is, in fact, electrically a bit larger than its physical dimensions due to the fringing fields. The deviation between electrical and physical size is mainly dependent on the PC board thickness and dielectric constant.

A better approximation for the resonant length is:

$$L \approx 0.49 \lambda_d = 0.49 \frac{\lambda_0}{\sqrt{\epsilon_r}}.$$

This formula includes a first order correction for the edge extension due to the fringing fields, with:

- L = resonant length
- λ_d = wavelength in PC board
- λ_0 = wavelength in free space
- ϵ_r = dielectric constant of the PC board material

Other parameters that will influence the resonant frequency:

- Ground plane size
- Metal (copper) thickness
- Patch (impedance) width

2.6 Antenna Gain

Antenna gain relates the intensity of an antenna in a given direction to the intensity that would be produced by a hypothetical ideal antenna that radiates equally in all directions or is isotropically and has no losses. Since the radiation intensity from a lossless isotropic antenna equals the power into the antenna divided by a solid angle of 4π steradians, we can write the following equation:

$$Gain = 4\pi \left(\frac{\text{Radiation Intensity}}{\text{Antenna Input Power}} \right)$$

$$Gain = 4\pi \left(\frac{U(\theta, \phi)}{P_{in}} \right) \quad \text{Dimensionless Units.}$$

The gain of a rectangular microstrip patch antenna with air dielectric can be very roughly estimated as follows. Since the length of the patch, half a wavelength, is about the same as the length of a resonant dipole, we get about 2 dB of gain from the directivity relative to the vertical axis of the patch. If the patch is square, the pattern in the horizontal plane will be directional, somewhat as if the patch were a pair of dipoles separated by a half-wave; this counts for about another (2-3) dB. Finally, the addition of the ground plane cuts off most or all radiation behind the antenna, reducing the power averaged over all directions by a factor of 2 (and thus increasing the gain by 3 dB). Adding this all up, we get about 7-9 dB for a square patch, in good agreement with more sophisticated approaches.

2.7 Methods to Enhance Gain in Microstrip Patch Antenna

Most compact microstrip antenna designs show decreased antenna gain owing to the antenna size reduction. To overcome this disadvantage and obtain an enhanced antenna gain, several designs for gain-enhanced compact microstrip antennas with the loading of a high permittivity dielectric superstrate or the inclusion of an amplifier-type active circuitry have been demonstrated.

Use of a high-permittivity superstrate loading technique gives an increase in antenna gain of about 10 dB with a smaller radiating patch. An amplifier-type active microstrip antenna as a transmitting antenna with enhanced gain and bandwidth has also been implemented.

2.8 Polarization

The plane wherein the electric field varies is also known as the polarization plane. The basic patch covered until now is linearly polarized since the electric field only varies in one direction. This polarization can be either vertical or horizontal depending on the orientation of the patch. A transmit antenna needs a receiving antenna with the same polarization for optimum operation. The patch mentioned yields horizontal polarization, as shown. When the antenna is rotated 90° , the current flows in the vertical plane, and is then vertically polarized.

A large number of applications, including satellite communication, have trouble with linear polarization because the orientation of the antennas is variable or unknown. Luckily, there is another kind of polarization circular polarization. In a circular polarized antenna, the electric field varies in two orthogonal planes (x and y direction) with the same magnitude and a 90° phase difference. The result is the simultaneous excitation of two modes, i.e. the TM₁₀ mode (mode in the x direction) and the TM₀₁ (mode in the y direction). One of the modes is excited with a 90° phase delay with respect to the other mode. A circular polarized antenna can either be Right-hand circular polarized (RHCP) or left-hand circular polarized (LHCP). The antenna is RHCP when the phases are 0° and 90° for the antenna in the figure below when it radiates towards the reader, and it is LHCP when the phases are 0° and 90° .

2.9 Bandwidth

Another important parameter of any antenna is the bandwidth it covers. Only impedance bandwidth is specified most of the time. However, it is important to realize that several definitions of bandwidth exists impedance bandwidth, directivity bandwidth, polarization bandwidth, and efficiency bandwidth. Directivity and efficiency are often combined as gain bandwidth.

2.9.1 Impedance bandwidth/return loss bandwidth

This is the frequency range wherein the structure has a usable bandwidth compared to certain impedance, usually $50\ \Omega$. The impedance bandwidth depends on a large number of parameters related to the patch antenna element itself (e.g., quality factor) and the type of feed used. The plot below shows the return loss of a patch antenna and indicates the return loss bandwidth at the desired S₁₁/VSWR (S₁₁ wanted/VSWR wanted). The bandwidth is typically limited to a few percent. This is the major disadvantage of basic patch antennas.

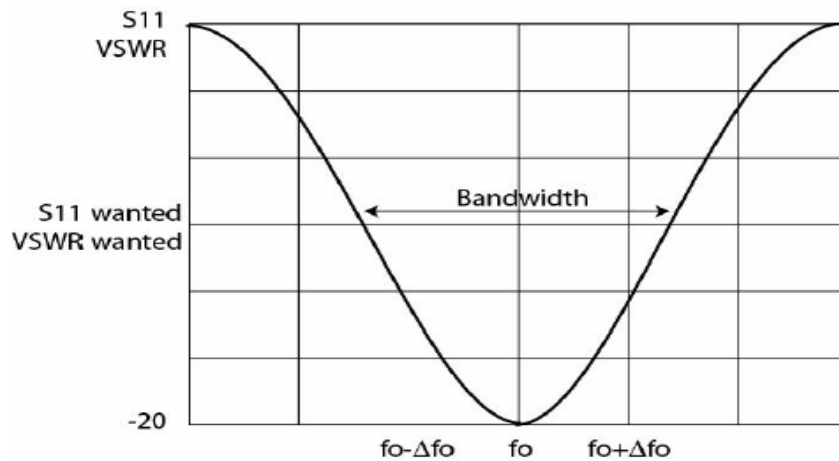


Figure 2.10 VSWR Bandwidth Calculation

Important note: Different definitions of impedance bandwidth are used, such as:

VSWR = 2:1 and other values, S11 values other than -10 dB, the maximum real impedance divided by the square root of two $[Z(\text{Re})/\sqrt{2}$, bandwidth], etc. This tends to turn selecting the right antenna for a specific application into quite a burden.

2.9.2 Directivity/gain bandwidth

This is the frequency range wherein the antenna meets a certain directivity/gain requirement (e.g., 1 dB gain flatness).

2.9.3 Efficiency bandwidth

This is the frequency range wherein the antenna has reasonable (application dependent) radiation/total efficiency.

2.9.4 Polarization bandwidth

This is the frequency range wherein the antenna maintains its polarization.

2.9.5 Axial ratio bandwidth

This bandwidth is related to the polarization bandwidth and this number expresses the quality of the circular polarization of an antenna.

Chapter 3

RECTANGULAR PATCH ANTENNA

3.1 Introduction

Microstrip antennas are among the most widely used types of antennas in the microwave frequency range, and they are often used in the millimeter-wave frequency range as well [1, 2, 3]. (Below approximately 1 GHz, the size of a microstrip antenna is usually too large to be practical, and other types of antennas such as wire antennas dominate). Also called patch antennas, microstrip patch antennas consist of a metallic patch of metal that is on top of a grounded dielectric substrate of thickness h , with relative permittivity and permeability ϵ_r and μ_r as shown in Figure 3.1 (usually $\mu_r=1$). The metallic patch may be of various shapes, with rectangular and circular being the most common, as shown in Figure 3.1

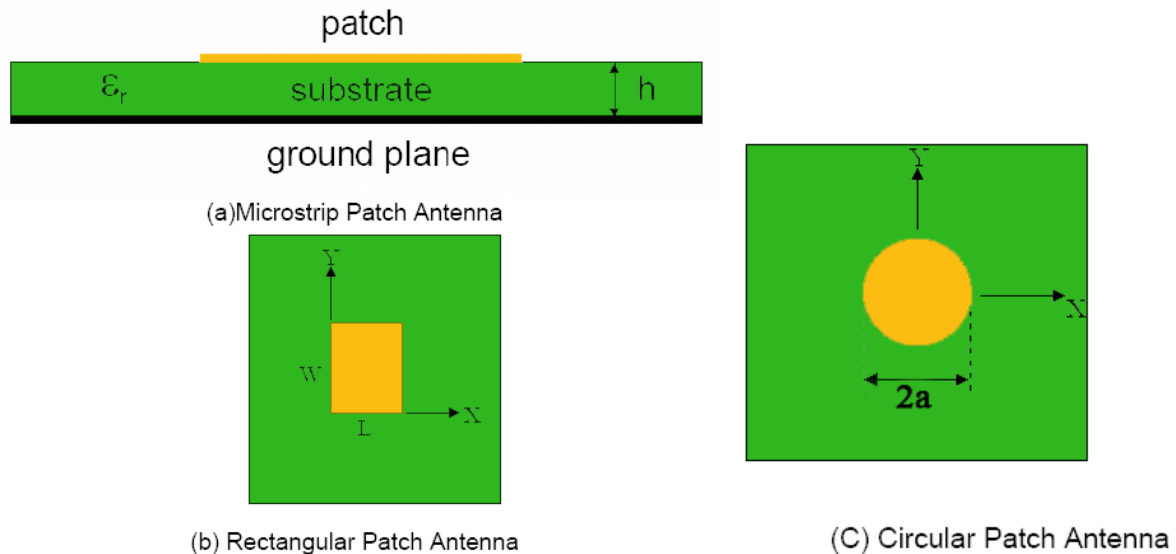


Figure 3.1 Rectangular & Circular Patch Antenna

Most of the discussion in this section will be limited to the rectangular patch, although the basic principles are the same for the circular patch. (Many of the CAD formulas presented will apply approximately for the circular patch if the circular patch is modeled as a square patch of the same area.) Various methods may be used to feed the patch, as discussed below. One advantage of the microstrip antenna is that it is usually low profile, in the sense that the substrate is fairly thin. If the substrate is thin enough, the antenna actually becomes “conformal,” meaning that the

substrate can be bent to conform to a curved surface (e.g., a cylindrical structure). A typical Substrate thickness is about $0.02 \lambda_0$. The metallic patch is usually fabricated by a photolithographic etching process or a mechanical milling process, making the construction relatively easy and inexpensive (the cost is mainly that of the substrate material). Other advantages include the fact that the microstrip antenna is usually lightweight (for thin substrates) and durable.

Disadvantages of the microstrip antenna include the fact that it is usually narrowband, with bandwidths of a few percent being typical. Some methods for enhancing bandwidth are discussed later, however. Also, the radiation efficiency of the patch antenna tends to be lower than some other types of antennas, with efficiencies between 70% and 90% being typical.

3.2 Basic Principles of Operation

The metallic patch essentially creates a resonant cavity, where the patch is the top of the cavity, the ground plane is the bottom of the cavity, and the edges of the patch form the sides of the cavity. The edges of the patch act approximately as an open-circuit boundary condition. Hence, the patch acts approximately as a cavity with perfect electric conductor on the top and bottom surfaces, and a perfect “magnetic conductor” on the sides. This point of view is very useful in analyzing the patch antenna, as well as in understanding its behavior. Inside the patch cavity the electric field is essentially z directed and independent of the z coordinate. Hence, the patch cavity modes are described by a double index (m, n) . For the (m, n) cavity mode of the rectangular patch the electric field has the form

$$E_z(x, y) = A_{mn} \cos\left(\frac{m\pi x}{L}\right) \cos\left(\frac{n\pi y}{W}\right)$$

Where L is the patch length and W is the patch width. The patch is usually operated in the $(1, 0)$ mode, so that L is the resonant dimension, and the field is essentially constant in the y direction. The surface current on the bottom of the metal patch is then x directed, and is given by

$$E_z(x, y) = A_{mn} \cos\left(\frac{m\pi x}{L}\right) \cos\left(\frac{n\pi y}{W}\right)$$

For this mode the patch may be regarded as a wide microstrip line of width W , having a resonant length L that is approximately one-half wavelength in the dielectric. The current is maximum at the centre of the patch, $x = L/2$, while the electric field is maximum at the two “radiating” edges, $x = 0$ and $x = L$. The width W is usually chosen to be larger than the length ($W = 1.5 L$ is typical) to maximize the bandwidth, since the bandwidth is proportional to the width. (The width should be kept less than twice the length, however, to avoid excitation of the $(0, 2)$ mode.)

At first glance, it might appear that the microstrip antenna will not be an effective radiator when the substrate is electrically thin, since the patch current in (2) will be effectively shorted by the close proximity to the ground plane. If the modal amplitude A_{10} were constant, the strength of the

radiated field would in fact be proportional to h . However, the Q of the cavity increases as h decreases (the radiation Q is inversely proportional to h). Hence, the amplitude A_{10} of the modal field at resonance is inversely proportional to h . Hence, the strength of the radiated field from a resonant patch is essentially independent of h , if losses are ignored. The resonant input resistance will likewise be nearly independent of h . This explains why a patch antenna can be an effective radiator even for very thin substrates, although the bandwidth will be small.

3.3 Resonant Frequency

The resonance frequency for the (1, 0) mode is given by

$$f_0 = \frac{c}{2L_e\sqrt{\epsilon_r}}$$

Where c is the speed of light in vacuum. To account for the fringing of the cavity fields at the edges of the patch, the length, the effective length L_e is chosen as $L_e = L + 2\Delta L$

The Hammerstad formula for the fringing extension is

$$\frac{\Delta L}{h} = 0.412 \left(\frac{(\epsilon_{eff} + 0.3) \left(\frac{W}{h} + 0.264 \right)}{(\epsilon_{eff} - 0.258) \left(\frac{W}{h} + 0.8 \right)} \right)$$

Where,

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left(1 + \frac{12h}{W} \right)^{-1/2}$$

Chapter 4

MICROSTRIP PATCH ANTENNA AND RESULTS

4.1 Design Specifications

The three essential parameters for the design of a rectangular Microstrip Patch Antenna:

- Frequency of operation (f_o): The resonant frequency of the antenna must be selected appropriately. The Mobile Communication Systems uses the frequency range from 2100-5600 MHz. Hence the antenna designed must be able to operate in this frequency range. The resonant frequency selected for my design is 2.4 GHz.
- Dielectric constant of the substrate (ϵ_r): The dielectric material selected for our design is RT Duroid which has a dielectric constant of 2.45. A substrate with a high dielectric constant has been selected since it reduces the dimensions of the antenna.
- Height of dielectric substrate (h): For the microstrip patch antenna to be used in cellular phones, it is essential that the antenna is not bulky. Hence, the height of the dielectric substrate is selected as 1.58 mm.

Hence, the essential parameters for the design are:

- $f_o = 2.4$ GHz
- $\epsilon_r = 2.45$
- $h = 1.58$ mm

Step 1: Calculation of the Width (W):

The width of the Microstrip patch antenna is given as:

$$W = \frac{c}{2f_o \sqrt{\frac{(\epsilon_r + 1)}{2}}}$$

Substituting $c = 3.00\text{e}+008$ m/s, $\epsilon_r = 2.45$ and $f_o = 2.4$ GHz, we get:

$$W = 0.0475 \text{ m} = 47.5 \text{ mm}$$

Step 2: Calculation of Effective dielectric constant (ϵ_{reff}):

The effective dielectric constant is:

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[1 + 12 \frac{h}{W} \right]^{-\frac{1}{2}}$$

Substituting $\epsilon_r = 2.45$, $W = 47.5$ mm and $h = 1.58$ mm we get:

$$\epsilon_{reff} = \mathbf{2.3368}$$

Step 3: Calculation of the Effective length (L_{eff}):

The effective length is:

$$L_{eff} = \frac{c}{2f_o \sqrt{\epsilon_{reff}}}$$

Substituting $\epsilon_{reff} = 2.3368$, $c = 3.00 \times 10^8$ m/s and $f_o = 2.4$ GHz we get:

$$L_{eff} = \mathbf{0.0406 \text{ m} = 40.625 \text{ mm}}$$

Step 4: Calculation of the length extension (ΔL):

The length extension is:

$$\Delta L = 0.412h \frac{(\epsilon_{reff} + 0.3) \left(\frac{W}{h} + 0.264 \right)}{(\epsilon_{reff} - 0.258) \left(\frac{W}{h} + 0.8 \right)}$$

Substituting $\epsilon_{reff} = 2.3668$, $W = 47.5$ mm and $h = 1.58$ mm we get:

$$\Delta L = \mathbf{0.81 \text{ mm}}$$

Step 5: Calculation of actual length of patch (L):

The actual length is obtained by:

$$L = L_{eff} - 2\Delta L$$

Substituting $L_{eff} = 40.625$ mm and $\Delta L = 0.81$ mm we get:

$$L = 39 \text{ mm} = 39 \text{ mm}$$

Step 6: Calculation of the ground plane dimensions (L_g and W_g):

The transmission line model is applicable to infinite ground planes only. However, for practical considerations, it is essential to have a finite ground plane. It has been shown by [9] that similar results for finite and infinite ground plane can be obtained if the size of the ground plane is greater than the patch dimensions by approximately six times the substrate thickness all around the periphery. Hence, for this design, the ground plane dimensions would be given as:

$$L_g = 6h + L = 6(1.5) + 39 = 48 \text{ mm}$$

$$W_g = 6h + W = 6(1.5) + 47.5 = 56.5 \text{ mm}$$

Step 7: Determination of Inset feed depth (y_0):

An inset-fed type feed is to be used in this design. As shown in Figure 4.1, the feed depth is given by y_0 . The feed point must be located at that point on the patch, where the input impedance is 50 ohms for the resonant frequency. Hence, a trial and error method is used to locate the feed point.

In this case we use PSO to obtain the optimum feed depth, where the return loss (R.L) is most negative (i.e. the least value). According to [5] there exists a point along the length of the patch which gives the minimum return loss.

$$R_{in}(y = y_0) = R_{in}(y = 0) \cos^4(\pi y_0/L)$$

$$\text{Where, } R_{in}(y=0) = 0.5 * (G_1 \pm G_{12})$$

$$Z_c = \begin{cases} \frac{60}{\sqrt{\epsilon_{eff}}} \ln \left[\frac{8h}{W_0} + \frac{W_0}{4h} \right], & \frac{W_0}{h} \leq 1 \\ \frac{120\pi}{\sqrt{\epsilon_{eff}} \left[\frac{W_0}{h} + 1.393 + 0.667 \ln \left(\frac{W_0}{h} + 1.444 \right) \right]}, & \frac{W_0}{h} > 1 \end{cases}$$

Where,

$$G_1 = \begin{cases} \frac{1}{90} \left(\frac{W}{\lambda_0} \right)^2 & W \ll \lambda_0 \\ \frac{1}{120} \left(\frac{W}{\lambda_0} \right) & W \gg \lambda_0 \end{cases}$$

And

$$G_{12} = \frac{1}{120\pi^2} \int_0^\pi \left[\frac{\sin\left(\frac{k_0 W}{2} \cos \theta\right)}{\cos \theta} \right]^2 J_0(k_0 L \sin \theta) \sin^3 \theta d\theta$$

Using the first equation (assuming that Z_c in the second equation is 50Ω) where $R_{in}(y=y_0) = 50\Omega$

We get: $y_0 = 13 \text{ mm}$

4.2 Design Procedure (PSO/IE3D)

(a) **Design I** Using $\lambda/4$ Line (70Ω) [Outset Feed]

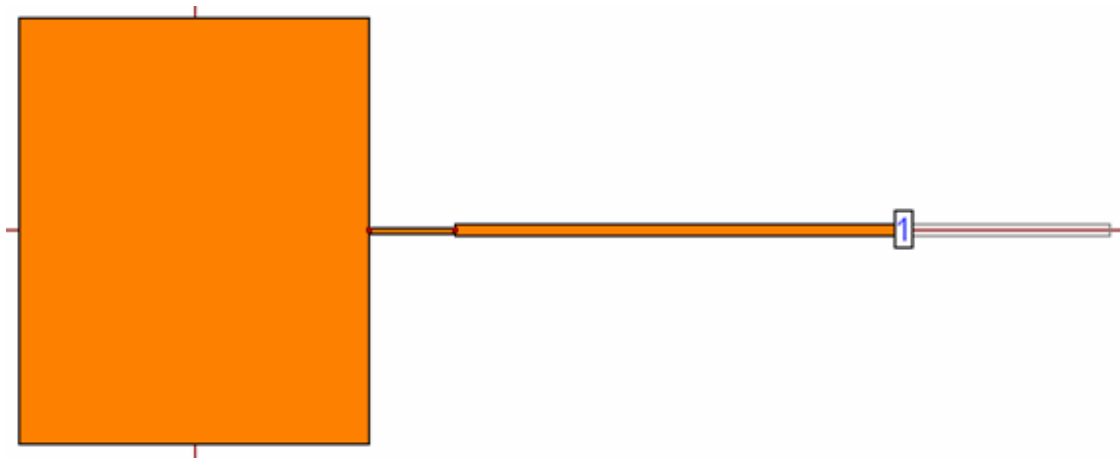


Figure 4.1 Microstrip patch antenna (with 70Ω *T-Line*) designed using IE3D

Design Specification:

$$\epsilon_{eff} = 2.3368$$

$$f_0 = 2.4$$

$$\lambda_0 = \{(3 \times 10^8 \text{ m/s}) \times 1000\} / (2.4 \times 10^9) = 125$$

$$\lambda_g = 125 / (\epsilon_{eff})^{(1/2)} = 81.79 \text{ [}\epsilon_{eff} = 2.3368\text{]}$$

$$\lambda_g/4 = 20.45$$

$$T\text{-Line } (70\Omega) = 20\text{mm}$$

$$T\text{-Line } (50\Omega) = 50\text{mm}$$

(b) Design II Using 50Ω T-Line [Inset Feed]

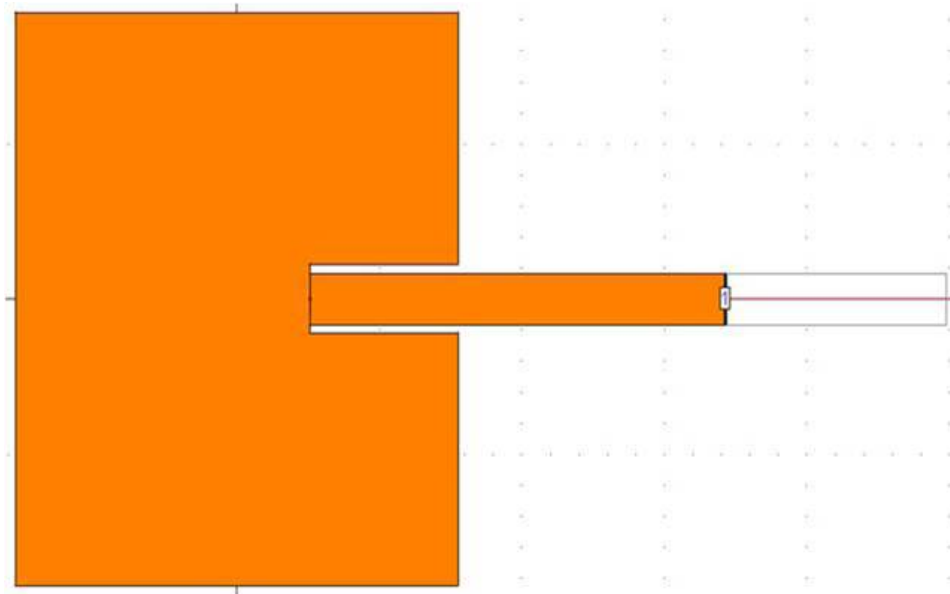


Figure 4.2 Microstrip patch antenna designed using IE3D

Design Specification:

$$f_o = 2.4 \text{ GHz}$$

$$\epsilon_r = 2.45$$

$$h = 1.58 \text{ mm}$$

$$L = 39.4 \text{ mm}$$

$$W = 46.9 \text{ mm}$$

$$y_0 = 13.2 \text{ mm}$$

(c) Design III Using EBGs [Inset Feed]

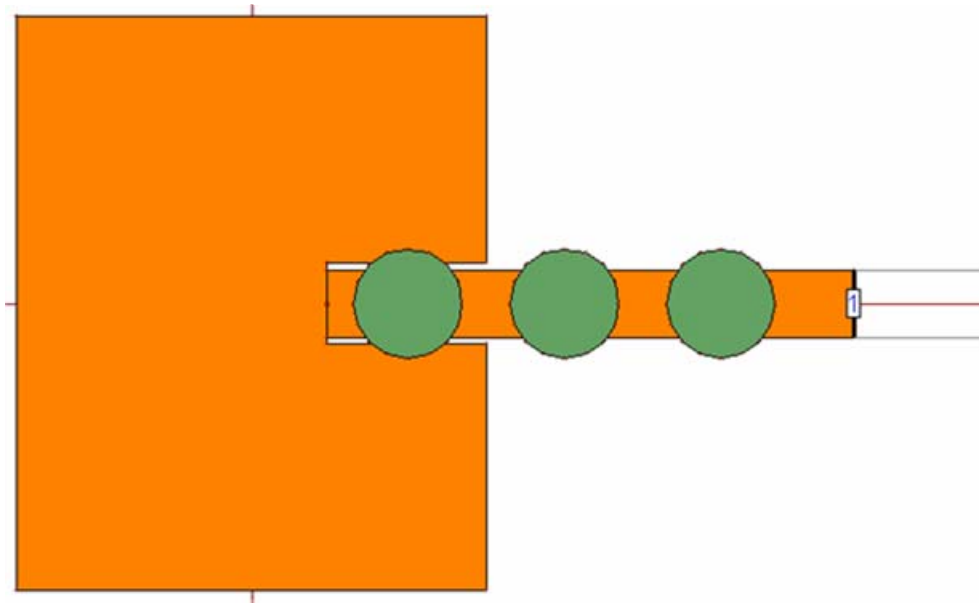


Figure 4.3 Microstrip patch antenna designed with EBGs using IE3D

Design Specification:

$$f_o = 2.4 \text{ GHz}$$

$$\epsilon_r = 2.45$$

$$h = 1.58 \text{ mm}$$

$$L = 39.4 \text{ mm}$$

$$W = 46.9 \text{ mm}$$

$$y_0 = 13.2 \text{ mm}$$

$$EBGS \text{ Radius} = 4.5 \text{ mm}$$

$$\text{Distance between EBGs} = 10 \text{ mm}$$

4.3 Simulation Setup and Results

The software used to model and simulate the Microstrip patch antenna is Zeland Inc's IE3D. IE3D is a full-wave electromagnetic simulator based on the method of moments. It analyzes 3D and multilayer structures of general shapes. It has been widely used in the design of MICs, RFICs, patch antennas, wire antennas, and other RF/wireless antennas. It can be used to calculate and plot the S_{11} parameters, VSWR, current distributions as well as the radiation patterns.

4.4 Return Loss

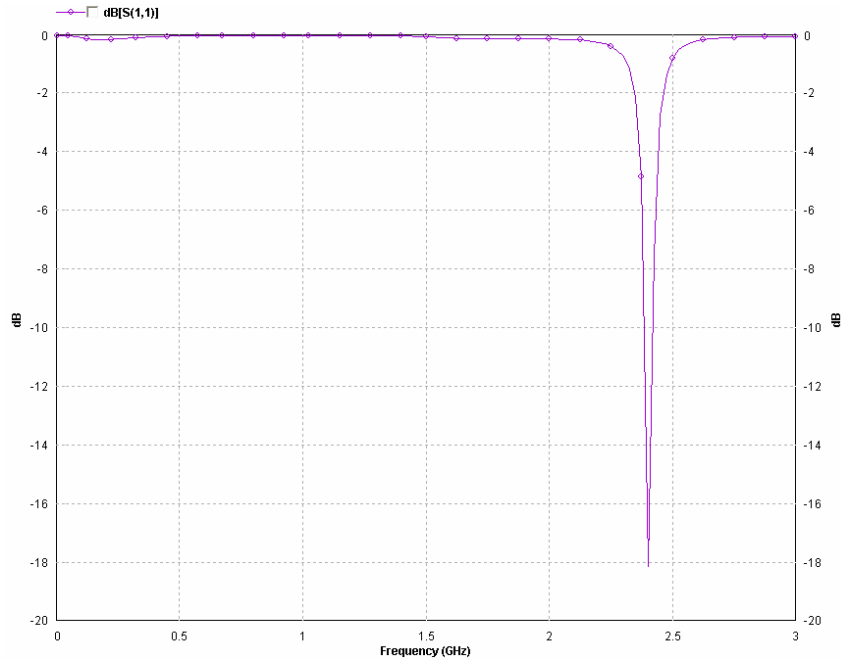


Figure 4.4 S-parameter plot for Return loss v/s frequency of (a) [Bandwidth: 0.02985]

The inset feed used is designed to have an inset depth of 13.2mm, feed-line width of 5.6mm and feed path length of 37mm. A frequency range of 2.2-3.5 GHz is selected and 151 frequency points are selected over this range to obtain accurate results.

The center frequency is selected as the one at which the return loss is minimum. As described in chapter 2, the bandwidth can be calculated from the return loss (RL) plot. The bandwidth of the antenna can be said to be those range of frequencies over which the RL is greater than -9.5 dB (9.5 dB corresponds to a VSWR of 2 which is an acceptable figure). Using PSO, the optimum feed depth is found to be at $Y_0 = 13.2\text{mm}$ where a RL of -27 dB is obtained. The bandwidth of the antenna for this feed point location is calculated (as shown below in Figure 4.4) to be 23.28 MHz and a center frequency of 1.9120 GHz are obtained which is very close to the desired design frequency of 1.9 GHz.

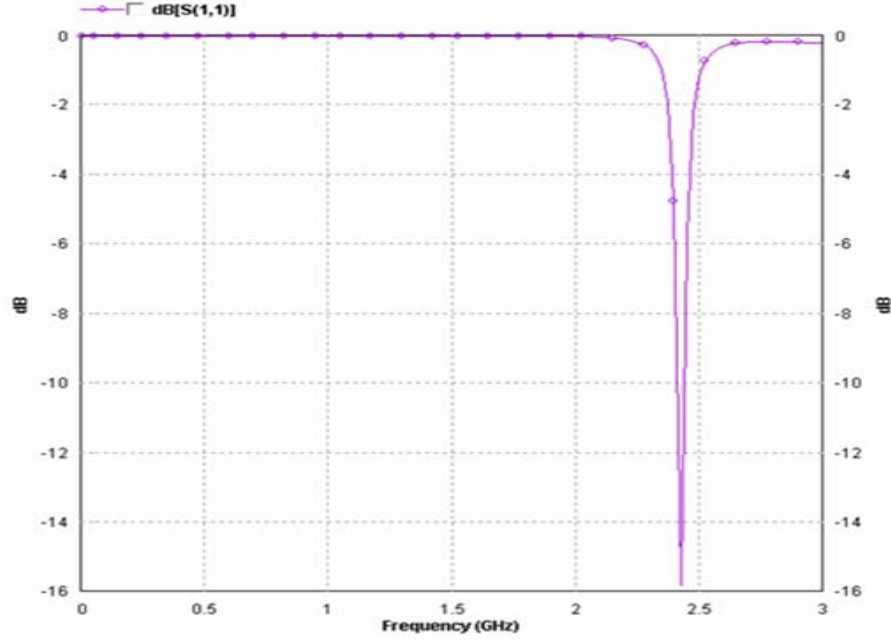


Figure 4.5 S-parameter plot for Return loss v/s frequency of (b) [Bandwidth: 0.02767GHz]

4.5 Development Model

We use to pre-emptive parameters to check the veracity of the PSO matlab code, before we begin to optimize the parameters of the Microstrip patch antenna.

4.5.1 Case I: Resonant frequency

We calculate the resonant frequency a Microstrip antenna, using its parameters like width (W), length (L), permittivity of the substrate (ϵ_r) and height (h) of the substrate. We apply Particle Swarm Optimization technique for optimization of ΔL . The optimized ΔL is used for calculating the resonant frequency of rectangular Microstrip patch antenna.

4.5.2 Case II: Feed point calculation

The input impedance of rectangular Microstrip patch antenna is a vital parameter in deciding the amount of input power delivered to the antenna, thus, reducing the coupling effect of the RF signal to the nearby circuits. The calculation of an exact 50 ohms input impedance of a rectangular Microstrip patch antenna becomes extremely difficult when the antenna size is drastically small. In this paper, an attempt has been made to exploit the capability of PSO technique to calculate the input impedance by searching the feed point position. The feed point is calculated by using below equation which is optimized by PSO technique to get accurate results.

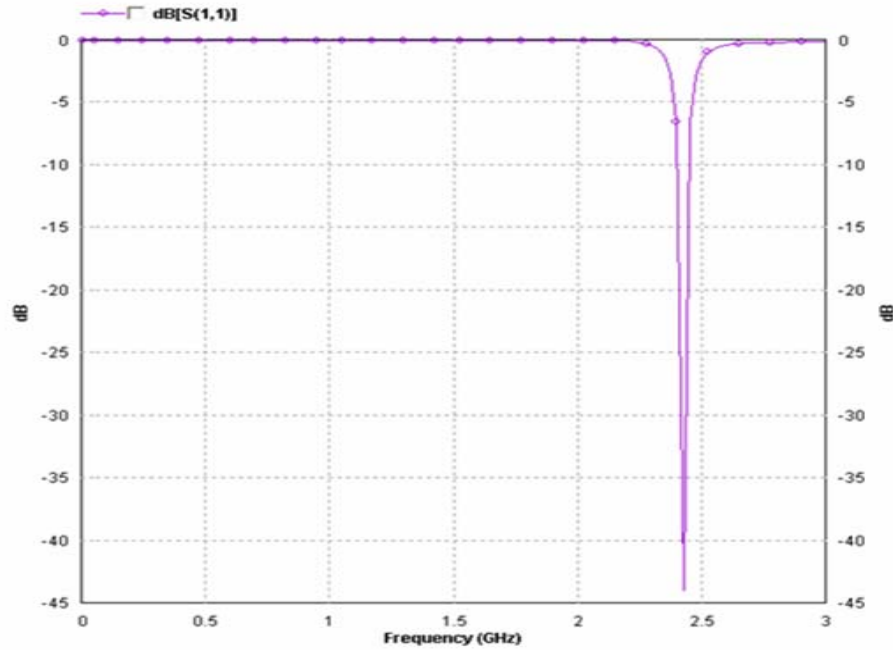
$$R_{in}(y = y_0) = R_{in}(y = 0) \cos^4(\pi y_0/L).$$


Figure 4.6 S-parameter plot for Return loss v/s frequency of (c) [Bandwidth: 0.04548GHz]

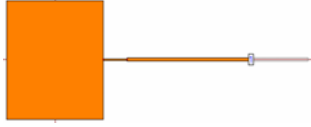
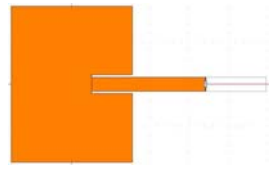
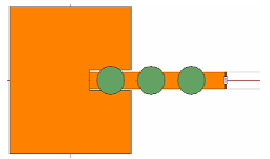
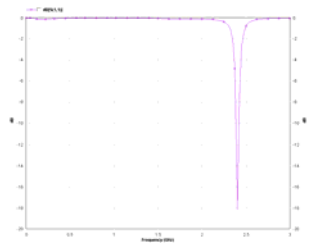
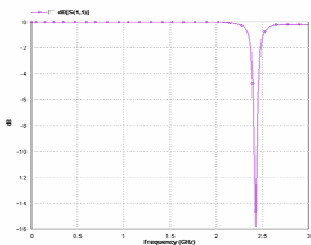
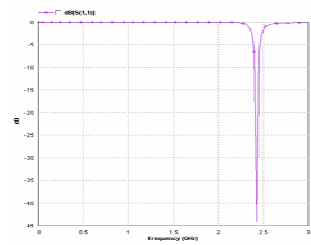
Serial	Design I	Design II	Design III
1			
2			
3	<p>Bandwidth 0.02985 GHz</p> <p>Depth -18dB</p>	<p>Bandwidth 0.02767GHz</p> <p>Depth -16dB</p>	<p>Bandwidth 0.04548GHz</p> <p>Depth -44dB</p>

Table 4.1 Comparison between three designs of Microstrip patch antenna

We have found that if we use EBGs on transmission line that we have shown in this figure then get the best output for this design and we proved that if we use EBGs then we will get an exclusive output of antenna. By integrating or differentiating our model it can be used in industrial purposes. The output will serve better than ever before.

Chapter 5

CONCLUSION AND FUTURE PROSPECTS

We have designed three wideband microstrip patch antennas. The characteristics of proposed antennas have been investigated through different parametric studies using IE3D simulation software. The proposed antennas have achieved good impedance matching, stable radiation patterns, and high gain. The phi-shaped antenna can be used for Wireless LAN application in the frequency range 5.2 to 5.8 GHz. Fabrication and Verification of simulated results can be carried out in future.

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